DOCUMENT RESUME

ED 182 564 CE 024 249

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TITLE Nuclear Technology. Course 26: Nondestructive Examination (NDE) Techniques I. Module 26-4, Liquid Penetrant Tests.
INSTITUTION General Physics Corp., Columbia, Md.
SPONS AGENCY Office of Education (DHEW), Washington, D.C.
PUB DATE 79
CONTRACT 300-77-0340
NOTE 63p.; Small, light type in figures may not reproduce well; For related documents see CE 024 245-298

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Course Content; Energy; Learning Activities; Learning Modules; *Nuclear Physics; Postsecondary Education; *Quality Control; Teaching Guides; *Technical Education; *Tests
IDENTIFIERS Hydrostatics; Nuclear Energy; Nuclear Energy Occupations; *Nuclear Power Plant Technicians; *Nuclear Technology

ABSTRACT

This fourth in a series of seven modules for a course titled Nondestructive Examination (NDE) Techniques I describes liquid penetrant examination which provides an effective method of detecting undesired, invisible surface discontinuities. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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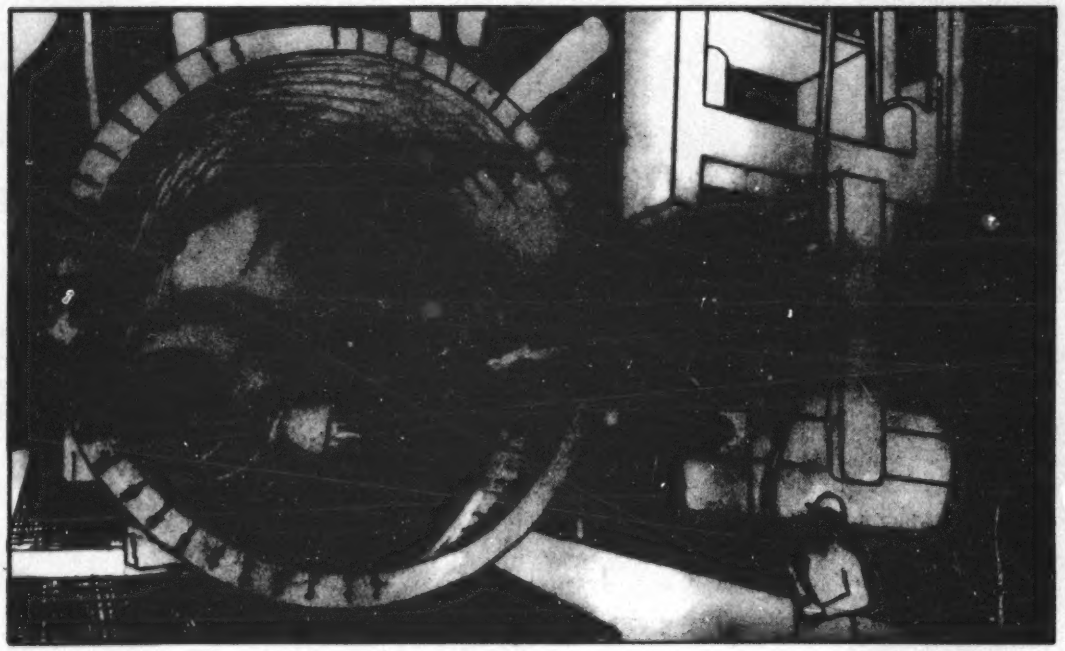
NUCLEAR TECHNOLOGY

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-4 Liquid Penetrant Tests



CE 024 249

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

Module 26-1	Visual Tests
Module 26-2	Leak Tests
Module 26-3	Hydrostatic Tests
Module 26-4	Liquid Penetrant Tests
Module 26-5	Fundamentals of Raidography
Module 26-6	Radiography Inspection
Module 26-7	Radiographic Specifications and Code Requirements

The material in this module was developed by General Physics Corporation under a contract with the United States Department of Health, Education and Welfare, Office of Education, Contract Number 300770340. Contractors undertaking such projects are encouraged to express freely their professional judgment in the conduct of the project. Therefore, points of view or opinions stated do not necessarily represetn official Office of Education position or policy.

This module was prepared by John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Surface of parts must not contain discontinuities which adversely affect the function or service of the part. Liquid penetrant examination provides an effective method of detecting undesired surface discontinuities which are invisible to the unaided eye. It is widely used throughout the nuclear industry.

Personnel who perform liquid penetrant examination and who establish its specific techniques are required to be certified inspectors. Certification is based on training and examination of each individual. This module parallels the training program recommended for candidates for certification.

A number of terms are introduced by this module. The student/trainee should refer to the glossary at the end of the module as each new term is encountered.

Nuclear QA/QC technicians may serve as liquid penetrant inspectors, establish test techniques, or monitor the performance of liquid penetrant examinations. This module contains ample information to support the performance of any of these tasks.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Briefly describe the historical development of the liquid penetrant examination method.
2. Name the fundamental principle of operation and describe its application to liquid penetrant examination.
3. Name at least four factors affecting penetrability and discuss the effects of each.
4. List the essential steps for performing the test and describe how each step is performed when given the name of any one of three liquid penetrant methods described by this module.
5. Discuss the importance and precautions associated with the step in general or its connection with a given penetrant method when given any of the six essential steps of liquid penetrant examination.
6. Name and describe the two systems for classifying penetrants.
7. Compare the sensitivity of the three liquid penetrant examination methods described by this module in respect to rough surface, fine cracks, and shallow, open discontinuities.
8. State three advantages and two disadvantages of the method when given any of the three liquid penetrant examination methods described by this module.
9. Distinquish the terms discontinuity, indication and defect.
10. Describe the use of black light lamps including purpose, filter, darkened inspection area, darkness adaptation, and safety precautions.
11. Name three classifications of defects; given a description of product, identify typical defects and their classification.

12. State two rules with respect to the point in time where required liquid penetrant examination is performed.
13. Describe the physical, written, and operational examination criteria upon which personnel certification is based.
14. State seven items which must be included in any liquid penetrant procedure.
15. Demonstrate the capability of examining a part by liquid penetrant examination.

NOTES TO INSTRUCTOR / STUDENT

Advance preparation will be necessary for the exercises recommended by this module. In this regard, advance consideration should be given to the methods and materials to be used with regard to penetrant methods and materials, the exercises in this module suggest the use of portable test kits which are available from most suppliers of penetrants. With regard to parts to be tested, parts with surface discontinuities are preferred. Sources include weld shops, metal working shops, junk yards, scrap parts from nearby industries. Also, a decision is necessary on whether aluminum comparative test panels will be used. Aluminum alloy sheet or strip, flame heating source, and 950°F temperature melting crayon are needed to fabricate these panels. See Exercise #3.

SUBJECT MATTER

BRIEF HISTORY OF LIQUID PENETRANT TESTING

Since the earliest uses of metals, means of detecting cracks have been explored. For many centuries, tests consisted of relatively crude methods of detecting cracks. Load tests, consisting of applied weights or pressurized fluids, determined if failure would occur at design loads. Some items, such as bells, were struck blows to determine if they "sounded right".

Nineteenth and twentieth century technology continuously placed greater demand for test methods of greater sensitivity. In the 1920's, radiography came into wide-spread use for examining metals. However, while it proved highly satisfactory for detecting internal cracks, its sensitivity to surface cracks, particularly shallow ones, was less than satisfactory. In the 1930's, Magnaflux Corporation developed and patented a magnetic particle examination method which was marketed under the trade name "Magnaflux". Their method proved highly reliable and sensitive to surface cracks. However, its application is limited to ferrous metals which are capable of being magnetized. For non-ferrous metals, detection of surface cracks depended on such methods as etching, anodizing and brittle lacquer. All of these methods depended on very careful visual examination and were not particularly sensitive to very fine or shallow surface cracks.

A forerunner of modern liquid penetrant examination was the Oil and Whiting method employed by the railroad industry. Components were soaked in hot oil which tended to enter any surface cracks. Subsequently, the component was then struck a blow or vibrated to "work" the oil out of the cracks. Oil stain on the chalk indicated the presence of cracks. This method was relatively insensitive to fine or shallow cracks.

The growth of the aircraft industry during World War II accelerated demands for more sensitive methods for detecting surface cracks. In particular, detection of fine fatigue cracks were of major concern. In the early 1940's, the work of R. C. Switzer of Switzer Brothers, Inc., led to a U.S. patent issued October 14, 1941 on the broad application of flourescent and color-contract penetrants. Later, Magnaflux Corporation in collaboration with the Switzer Brothers refined the flourescent penetrant method and obtained a U.S. patent under the trade name "Zyglo". Zyglo was quickly adopted by aircraft industries as a reliable and sensitive method of testing non-ferrous metals. Subsequently, Magnaflux Corporation and others developed the additional penetrant materials and techniques available today.

THEORY

General

Liquid penetrant examination is a nondestructive test which is capable of detecting discontinuities open to the surface of nonporous materials. It is based on the ability of a fluid to "penetrate" surface discontinuities and, subsequently, to come back out of discontinuities to form "indications". The fluids used are termed "penetrants".

Capillary Action

The fundamental principle upon which the operation of liquid penetrant examination depends is capillary action. Capillary attraction generates forces which cause a liquid to rise spontaneously in a small diameter tube. It is these same forces which cause penetrants to enter surface discontinuities. When "excess" penetrant is removed from the surface, the reservoirs of penetrant within discontinuities

have a natural tendency to creep back out, thereby forming indications.

For penetration of discontinuities to occur, the penetrant must intimately contact the surface to be examined. Therefore, the surface must be clean and exposed to the penetrant. Rusts, scale, oil, grease, water, acids, dirt, lint and other foreign surface materials tend to block the penetrant from discontinuities and give high potential for not detecting all discontinuities. Coated surfaces, e.g. painted surfaces, are totally unsuitable for liquid penetrant examinations in that the coating prevents contact between the penetrant and surface.

Penetrability

The penetrability of penetrants depends on a number of factors with no single factor being solely responsible. The primary factors affecting penetrability are viscosity, surface tension, wetting ability, surface condition, and nature of the defect.

- viscocity - More than ability to penetrate, viscosity affects speed of penetration. A more viscous penetrant moves more slowly and offers more resistance to the forces drawing the penetrant into a discontinuity. However, a very fluid penetrant gravitationally drains quickly away from the surface such that a sufficient reservoir of penetrant may not remain. Penetrants have a viscosity on the order of 10 to 29 times that of water.
- surface tension - Surface tension must be relatively high for good pentrability. However, water which has a high surface tension, is a poor penetrant. Surface tensions of penetrants are on the order of ½ that of water.

- wetting ability - The ability of a penetrant to wet the surface is very important. Wetting ability is measured by the angle between the liquid and the surface at the point of contact as the liquid advances along the surface. As this contact angle decreases, wetting ability increases. Good penetrants have a very small contact angle since penetrability is directly proportional to the product of the surface tension and the cosine of the contact angle.
- surface condition - The surface to be examined primarily affects the contact angle (wetting ability) of the penetrant. The type of material, surface roughness, and cleanliness of the surface influence pentrability of a given penetrant. Manufacturers of penetrants test their products for a variety of surface conditions to determine suitability for various applications.
- nature of the defect - The width and roughness of discontinuities affect penetrability. Very tight cracks and high roughness require higher pressure from capillary action for penetration to occur. However, the natural unevenness of discontinuities tends to reduce the theoretical pressure required for penetration. Apparently, the higher capillary pressure in the tightest areas forces air out of the wider areas such that penetration results. Some penetrants have been shown to penetrate cracks as narrow as .00001 inch.

Sensitivity

Sensitivity of liquid penetrant examination refers to a qualitative measure of the ability to detect discontinuities. Numerical values are not assigned. When considering sensitivity, a number of factors must be examined. The specific type of penetrant, the surface to be examined, the nature of the

discontinuities to be detected, and the specific technique employed are the primary factors affecting sensitivity. Normally, sensitivity is discussed in terms of the type of discontinuity, the relative comparison among types of penetrant, or effect of technique. For example, "sensitive to broad, shallow discontinuities"; "not sensitive to broad, shallow discontinuities"; "Type A penetrant is more sensitive to fine cracks than Type B penetrant"; "foreign surface material reduces sensitivity".

General Application

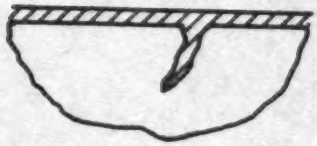
Liquid penetrant examination offers an excellent means of nondestructively examining nonporous materials for discontinuities open to the surface. If the material is porous, penetrant enters all porous areas and creeps back out as "indications" such that a meaningful examination is impossible. Therefore, liquid penetrant examination is not suitable for such materials as rubber, unglazed ceramics, wood, fibre board, paper products, etc. Instead, liquid penetrant examination is applicable to nonporous materials such as metals, glass, and porcelian.

SIX ESSENTIAL STEPS

General

Each liquid penetrant examination employs six essential steps regardless of the specific type of penetrant used. These essential steps are precleaning, application of penetrant, removal of excess penetrant, developing, inspection, and postcleaning. A highly simplified illustration of the process is shown in Figure 26-4-1.

a. Clean Surface With Flaw



b. Penetrant Applied

c. Excess Penetrant Removed

d. Developing and Inspection

Figure 26-4-1. Simplified Illustration of PT Examination

Precleaning (Surface Preparation)

Precleaning activities are concerned with cleanliness and surface condition. For this reason, this essential step is sometimes termed surface preparation.

The principle of capillary attraction demands that the penetrant and surface discontinuity be in intimate contact. Dirt, oil, grease, lint, scale weld spatter, or other "foreign" matter prohibit such intimate contact and interfere with penetration. Surface coatings, such as paint, make penetration impossible. Therefore, it is essential that the surface be clean and exposed.

Selection of a precleaning method is on a case basis. Factors involved are the type of "foreign" material to be removed, the type of material and its configuration, and speed of the cleaning method. In each instance, the cleaning

method must adequately clean the surface while not deteriorating or "attacking" the surface. For nickel base materials, cleaning agents must be essentially free of sulfur and for austenitic stainless steels and titanium alloys, cleaning agents must be essentially free of halogens. These agents tend to promote cracking of the metals in a temperature-stress environment.

For coated surfaces, the first step of precleaning is removal of the coating. For painted surfaces, a suitable paint remover is used. For uncoated surfaces, possible cleaning methods include detergent wash and water rinse, organic solvents, vapor degreasing, and ultrasonic cleaning. A comparison of these methods is given in Table 26-4-1.

Vapor degreasing is a preferred cleaning method for oily parts. It not only cleans the surface but, more than the other methods, removes oil from surface discontinuities. Thus penetration is aided. However, vapor degreasing will not remove rust. An intermediate cleaning method, such as pickling or hot alkaline is necessary to remove rust.

The specific cleaning method and cleaning agents must generally meet three requirements. First, it must remove oil and grease which is commonly found on surfaces from prior processing steps. Secondly, it must be free of contaminants such as sulfur and halogens. Thirdly, it must leave minimum residue on the surface.

Table 26-4-1. Precleaning Methods

Method	Soils Removed	Limitation	Remarks
Detergent Cleaning	Organic: grease, oils cutting fluids, etc. Hot alkaline is effective for inorganic scales, rusts, sands	Except for alkaline detergent cleaning and expecially hot alkaline cleaning, not totally effective for scale and rust.	Followed by rinsing and drying. Possible skin and eye irritant. Nonflammable.
Solvent Cleaning	Organic: grease, oil waxes, sealants, etc.	Ineffective for scale, rust, welding flux, and other inorganic soils.	Flammable. Possible toxic, skin irritant.
Vapor Cleaning	Preferred for organic: grease, oils, etc.	Ineffective for inorganic soils. May not remove resinous soils such as plastics, paints, varnishes.	Parts must be cooled prior to PT.
Ultrasonic Cleaning	With detergent fluid: effective for inorganic soils. With solvent fluid: Effective for organic soils.	Equipment limits to small to medium size items.	Followed by hot drying.
Paint Removal	Paints		Followed by rinsing and drying. Normally flammable. Possibly toxic skin irritant.

Grit and shot blasting and wire brushing are unacceptable cleaning methods for the liquid penetrant precleaning step. Grit or shot tends to peen the surface such that discontinuities may be closed and, therefore, prevent penetration. When grit or shot blasting is used in the fabrication processes on surfaces which must be subsequently examined by liquid penetrant, an intermediate step is added to chemically remove the blasted surface by pickling in an acid bath.

Wire brushing simply does not adequately clean the surface. Power wire brushing also has a risk of smearing metal over discontinuities such that they are not detectable.

The surface condition of concern is roughness. Excessive roughness may prohibit adequate precleaning or trap penetrant and appear as indications. Entrapment of penetrant is normally the major result of surface roughness. Therefore, a roughness limit is normally established for each method of removing excess penetrant.

Once the surface is clean and within roughness limits, the surface must be dried. Otherwise, the cleaning agent may of itself interfere with penetration. This is especially true of water since water is insoluble in many penetrants and seriously contaminates water washable penetrants. Drying is accomplished by forced hot air.

In summary, the precleaning step is essential to permit penetration. It consists of the substeps of surface preparation as necessary to remove excessive roughness, cleaning with an effective cleaning method, and drying to remove the cleaning solutions or agents.

Application of Penetrant

Prior to applying penetrant, the surface must be clean and exposed. It must be dry and free from materials from prior processing such as oil, acids and water.

Penetrants may be applied by dipping the item into the penetrant or by pouring, spraying or brushing the penetrant onto the item. When spraying is used with compressed air apparatus, a filter is placed in the air inlet line to prevent contamination by water, oil, or dirt sediment. Wiping the penetrant onto the part with saturated cloths is generally not acceptable because it tends to wipe away the penetrant. Regardless of the method employed, application of penetrant must meet the following criteria:

- temperature of the surface must be within limits - Excessively hot surfaces will evaporate the volatile constituents and leave residues which interfere with the test. When dipping is employed, parts may be as hot as about 200°F if they are allowed to cool to about ambient in the penetrant bath. Auxiliary cooling of the penetrant may be necessary if hot parts are continually dipped into penetrant. On the other hand, excessively cool parts and penetrants increase viscosity and reduce sensitivity. Therefore, temperature limits of 60°F minimum and 125°F maximum are typical.
- complete surface covering must be obtained - Application of penetrant must ensure filling of surface discontinuities. Therefore, a liberal amount of penetrant is applied over the entire surface to be examined. The examiner ensures a complete "wetting" of the surface by the penetrant. If the penetrant beads or doesn't adhere to the surface, either entrapped air (mostly in the dipping method) or foreign material on the surface are the likely culprits. Complete wetting means a liberal covering of penetrant but not submergence. When items are dipping into penetrant they are promptly removed and allowed to drain. In the event partial drying of penetrant is suspected, the part is redipped into the penetrant.

- specified penetration time must be allowed - Each type of penetrant requires some finite time to penetrate. This time is termed penetration time or dwell time. The type of discontinuity to be detected, the type of penetrant, and the temperature affect penetration time. Therefore, the optimum penetration time is established for the specific purpose of the examination, the type of penetrant used, and a specified temperature range. Dwell time ranges from 5 to 60 minutes dependent on the specific application. As dwell time increases, penetration and sensitivity increase. When tests must be conducted at temperatures lower than 60°F, long dwell times are established. Dwell time is measured from the time of application to the time of removal of excess penetrant.

Removal of Excess Penetrant

While application of penetrant purposely slops penetrant all over the surface, care is necessary in removal of excess penetrant. Insufficient removal of penetrant leaves a background of penetrant which masks, obscures, and interferes with true indications. Over-zealous removal of excessive penetrant extracts penetrant from discontinuities such that real indications may be totally removed. The success of the examination is greatly dependent on proper removal of excess penetrant.

The specific method of removing excess penetrant is dependent on the type of penetrant used as described later in this module. Regardless of the specific method used, removal of excess liquid penetrant must meet three objectives: (1) commence at the completion of the specified dwell time to allow proper penetration, (2) avoid insufficient removal of excess penetrant to preclude background indications which tend to

obscure real indications, and (3) avoid excessive removal of excess penetrant to preclude removal of real indications.

Developing

Developing consists of applying a material which acts as a blotter with respect to the penetrant. As penetrant creeps out of surface discontinuities, the developer absorbs it and promotes further withdrawal of penetrant from the discontinuities. Specific developing techniques depend on the type of developer as described later in this module. Regardless of the technique, developing must meet three objectives: (1) promote visibility of indications and not obscure or mask indications, (2) obtain a thin, uniform developer coating over the entire surface being examined to ensure development of indications within any area, and (3) not result in caking, puddling, or running of the developer in order to preclude masking of indications.

Each type of developer requires some amount of time to "pull" penetrant from discontinuities. This is on the order of 5 to 10 minutes minimum.

Inspection

Inspection commences after the specified minimum developing time and must conclude prior to expiration of the maximum developing time. Otherwise, reexamination of smaller surface areas is required in order to meet these time limits.

Inspection consists of two distinct parts: interpretation and evaluation. Interpretation means a determination which classifies indications as relevant or nonrelevant. Evaluation means a determination of the acceptability of relevant indications as compared to acceptance standards.

Indications are first interpreted as relevant or nonrelevant. If indications are judged to result from a cause other than discontinuities, they are considered nonrelevant. Possible causes of nonrelevant indications include surface roughness, geometry of the part, and inadequate techniques as described below.

- surface roughness - Rough surfaces make removal of excess penetrant difficult. Penetrant can "hide-out" within the rough surfaces and appear as indications upon development. Such indications tend to be fuzzy, blotchy, or of very irregular shape. Upon removal of developer, the inspector can visually see rough areas coinciding with location of such indications. When these nonrelevant indications are so large as to give potential for masking relevant indications, the rough areas are smoothed by grinding (or other means) and reexamined commencing with precleaning. Where small indications result from known surface roughness such that relevant indications are not masked, reexamination is not required.
- geometry of the part - Sharply recessed areas tend to result in indications solely due to inadequate removal of excess penetrant. Threads, slots and sharp fillets are examples of such geometries. Since overzealous removal of excess penetrant must be avoided, some residual penetrant is expected in these recesses. Careful techniques for excess penetrant removal coupled with skilled inspection permits adequate examination of these areas. Another geometry condition which yields nonrelevant indications is the mechanical joint. For example, a gear pressed onto a shaft provides a joint into which penetrant enters just like it enters a crack. Knowledge of the construction of the surface being examined make such nonrelevant indications easily

recognized. Such indications are ignored unless such profuse bleed-out occurs as to mask areas of consideration. In such instances, the item is re-examined.

- inadequate techniques - Nonrelevant indications can occur from inadequate precleaning, insufficent removal of excess penetrant, and accidental place-of penetrant onto surfaces after removal of excess penetrant. Many soils which should have been removed by precleaning are porous. When porous soils remain on the surface, non-relevant indications occur. Inadequate removal of excess penetrant results in a "blush" type of indication over a relatively large area. Sloppy or careless work practices can transfer penetrant onto the surface after removal of excess penetrant. Potential sources include penetrant from hands, handling equipment and baskets, and work surfaces and contact of a part with an area of bleed-out on another part. Normally, nonrelevant indications from inadequate techniques are blotchy, irregular in shape, or a background blush. When such non-relevant indications represent potential for masking or obscuring relevant indications, the part is re-examined.

Relevant indications appear as rounded or linear. Rounded indications are those where the length is no more than three times the width. This type of indication is indicative of surface porosity or inclusion of porous material on the surface. For example, gas blow holes and imbedded silicates open to the surface result in rounded indications. Linear indications are indicative of cracks, seams, laps, tears, and laminations. Such indications may range from relatively broad to very fine. Another category of discontinuities may give either rounded or linear indi-

cations. These are mostly induced flaws identified as nicks, gouges, and scratches. Also small laps and seams may give rounded indications. Sometimes, these rounded indications appear with a linear "pigtail". Finally, extremely tight cracks may appear as a series of rounded indications in a line. Such linearly disposed indications occur where bleed-out exists at various points along the crack.

All relevant indications are evaluated in terms of an acceptance standard. Typically, acceptance standards permit acceptance of the part if there are:

- no linear indications.
- no rounded indications in excess of a specified number.
- no rounded indications in excess of a specified diameter.
- not more than four linearly disposed indications where linearly disposed means those indications within a specified distance which touch a straight line connecting the center points of the outermost indications.

The acceptance standards are stated in terms of indication of size recognizing that penetrant indications are typically larger than the size of the associated discontinuity. Engineering establishes acceptance criteria based on those types and sizes of discontinuities which adversely effect the usefulness (function) of the item in service. Unacceptable discontinuities are termed defects. While each relevant penetrant indication represents a discontinuity, only those exceeding the acceptance standard represent a defect.

Post Cleaning

In most instances, items are cleaned soon after completion of inspection. The developer and penetrant as may be present typically interfere with subsequent processing or with service requirements. With either condition, post-cleaning is absolutely necessary. Even when neither of these conditions exist, items are typically cleaned for esthetics, i.e., so they do not appear dirty. Post cleaning is accomplished relatively soon after inspection because developers tend to fix on the part with time.

Any of the precleaning methods, except vapor degreasing, may be used for postcleaning. Frequently, a water rinse is adequate. Vapor degreasing is not used because it bakes the developer onto the part. If it is planned to re-examine the surface at some later time, the selected post-cleaning method must be capable of removing penetrant because penetrants in discontinuities eventually dry and are then very difficult to remove. This aspect has more importance when acceptable relevant indications must be repeated at some later time. For example, repeated tests of a test plate or repeated tests for consumer representatives.

TYPES OF PENETRANTS

Penetrants must exhibit a variety of characteristics which provide for a test that is sensitive to the types of discontinuities to be detected. In general, their sensitivity is described in terms of very fine cracks and shallow, open discontinuities because these flaws represent opposite extremes. Penetrability is extremely important for detecting fine cracks. On the other hand, ability to

remain in shallow, open flaws is very important during removal of excess penetrant if such flaws are to be detected. Penetrants are formulated to meet these and other desireable characteristics insofar as possible in relation to the application intended. This means that each type of penetrant is "best" for the application for which it was formulated. Desirable characteristics include the following:

- excellent penetrability for very fine openings.
- ability to remain in coarse openings.
- highly visible.
- easily cleanable from the surface without removal of much penetrant from discontinuities.
- inert with respect to the materials to be tested.
- stable under environmental conditions associated with storage and use.
- inexpensive.
- nonhazardous.

Classification of Penetrants

All penetrants are broadly classified by their visibility into two types: flourescent and color-contrast. Flourescent penetrants contain an additive which fluoresces when struck by light of a wavelength shorter than visible light by emitting light in the visible range. Color-contrast penetrants contain a dye which is visible by both color and contrast in comparison to surroundings.

All penetrants are further classified by the method of removing excess penetrant from the surface being examined. These classifications are water-washable, post-emulsifier, and solvent removable. Each of these may be flourescent or color-contrast penetrants, although those most widely used in nuclear power plant application are water-washable fluroescent, post-emulsifier fluorescent, and solvent removable color-contrast.

Fluorescent Penetrants

Fluorescent penetrants have an additive which emits visible light when struck by higher energy light. The higher energy light is standardized as peaking at 3650 Angstroms which is just outside the visible voilet range. Dyes are selected to be responsive to this "black light," and to emit with high intensity the desired color. With the proper concentration of fluorescent dye, such penetrants are highly visible with a contrast ratio on the order of 1000 to 1.

Fluorescent penetrants in nuclear power plant applications involve the terms fluorescent color, water washable, post-emulsifier, black light, and darkness adaptation as follows:

- fluorescent color - This term refers to the color of the light emitted by the fluorescent dye and it is dependent on the type of dye. It is normally in the yellow-green spectrum because the human eye is most sensitive to this color. However, automated equipment may use fluorescent penetrants which emit another color to be most sensitive to the photo-multiplier tubes.
- water-washable fluorescent penetrant - This is an oil-base penetrant with emulsifier and fluorescent dye additives. The emulsifying agent is dormant until it contacts water. When activated by water, the agent emulsifies the penetrant such that it can be washed away. The quantity of emulsifying agent is carefully controlled by the manufacturer to produce a penetrant which is removed from inspection surfaces by water spray without also quickly removing penetrant from discontinuities. Nonetheless, excess washing destroys indications. Also, this penetrant is seriously degraded if water contamination occurs.

- post-emulsifier fluroescent penetrant - This is an oil-base penetrant with fluorescent dye but without an emulsifier. Instead, an emulsifier is added at the completion of penetration time to permit washing excess penetrant with water. A finite time is necessary for the emulsifier to act on the penetrant. Emulsification times are selected which permit emulsification of penetrant on the surface but not in discontinuities. Thus, this penetrant is much less susceptable to over washing and attendant loss of sensitivity. Also, it is not so seriously impaired by water contamination as the water-washable penetrant. However, careful control of the emulsifying step is necessary.
- black light - This term is applied to the near-ultravoilet lights which are used with fluorescent penetrant examination. These lights must be sufficiently intense within the 3300 to 3900 Angstroms wave length range with little emission of light at other wave lengths. The 3300 to 3900 Angstroms wave length range is chosen because it is not harmful to living tissues. Because all types of black lights generate additional wave lengths, they are equipped with glass filters of a dense red-purple color to eliminate almost all visible light and the harmful ultravoilet waves of 3200 Angstroms and shorter. Black light should never be used without the filters or with cracked filters. Also inspectors should never look directly into a black light because temporary clouding of vision occurs in the same manner as looking into any strong light. Enclosed mercury vapor arc lamps are the most widely used black lights for fluorescent penetrant examina-

tion because they are quite capable of meeting the minimum intensity requirements. Regulated power supplies are sometimes used because line voltage fluctuations shorten the life of black lights.

- darkness adaptation - Fluorescent penetration inspection areas are purposely darkened to permit maximum visibility of indications. Upon entry to the darkened area, a person's eyes require some time to adjust to the different lighting level. Adjustment of the eyes to the lower lighting level is darkness adaptation. A minimum of five minutes should be allowed for darkness adaptation. If the inspector leaves the inspection area, another five minutes should be used upon reentry for adjusting to the darkness prior to recommencing inspection.

Color-Contrast Penetrants

Color-contrast penetrants employ a dye, usually red, which is visible by color and contrast with its surroundings. Red dyes are used almost exclusively because they give excellent color and contrast visiblity against white developers. Contrast ratios of 6 to 1 or 7 to 1 are typical.

Color-contrast penetrants are available as water-washable, post-emulsifier, and solvent removable. None require use of a black light. In nuclear power plant application, the solvent removable type is used almost exclusively.

TYPES OF DEVELOPERS

Developers are employed in liquid penetrant examination to enhance the visible evidence of penetrant indications. All developers serve as a blotter which absorbs

penetrant bleeding from discontinuities. The developer spreads penetrant indications to make them more visible by more light emitted or more area for color-contrast detection. In general, developers must exhibit the following characteristics:

- good blotting action.
- easily applied.
- non-fluorescent (particularly those used with fluorescent penetrants).
- adherent as a thin coating.
- readily removable.
- inert with respect to the parts to be tested.

There are three types of developers used in nuclear applications: dry powder, water-suspension, and solvent-suspension.

Dry Powder Developer

Dry powder developer consists of light, fluffy powders which form a thin dust coating on metallic parts. Their color is typically white and they must not be fluorescent in order to avoid interference with fluorescent penetrant indications.

Dry powder developer may be used with water washable and post-emulsifiable fluorescent penetrants. It is preferred over water-suspension developer on very rough surfaces. It is applied by either dipping the part into the powder or by spraying the powder onto the part. Vibrating the part, such as by shaking and tapping, removes excess powder. After inspection, water or solvent cleaning removes the developer.

Water-Suspension Developer

Water-suspension developers are furnished as a dry powder which is mixed with water by the user in accordance

with the manufacturer's directions. The concentration of the suspension greatly affects sensitivity. Excessive concentration leads to excessive coating in areas of poor drainage. Thick coatings tend to crack during the drying cycle. Insufficient concentration results in very thin coatings with less developing action. Therefore, precise mixing of the developer and agitation of tanks of the mixture are necessary.

Water-suspension developers are used with water-washable and post-emulsifiable fluorescent penetrants. It is applied by dipping the part or by hosing the developer onto the part. As with dry powder developers, the water-suspension developer must not contain fluorescent particles. It is preferred over dry powder developers on extremely smooth surfaces.

Solvent-Suspension Developers

The solvent-suspension developer is furnished premixed by manufacturers in sealed containers or pressure spray cans. Prior to use, the containers are agitated to ensure an evenly distributed suspension.

Application is by soft bristle brush or by spraying. Care is necessary to avoid running, puddling, and caking of the developer.

Solvent-suspension developer is used with the solvent-removable color-contrast penetrants. The developer solvent is highly volatile and rapidly evaporates leaving a coating of white particles which had been suspended. Prior to evaporation, the solvent tends to dissolve penetrant which is trapped in discontinuities and promotes bleed-out. The resultant white coating enhances color-contrast visibility of the red penetrant. The developer coating is removed, after inspection, by water or solvent washing.

WATER WASHABLE FLUORESCENT METHOD

Advantages and Disadvantages

The water washable fluorescent liquid penetrant examination method employs fluorescent dye and either dry powder or water-suspension developer. This method has the following advantages and disadvantages:

Advantages

- excellent visibility of indications under black light.
- readily automated.
- examines small parts (in a basket) as a unit: individual handling is required only for inspection.
- capable of examining a wide variety of shapes with equal speed.
- capable of examining rough surfaces.
- good for detecting a wide range of discontinuities.

Disadvantages

- unreliable for detecting open or shallow defects.
- susceptability of the penetrant suspension to contamination especially by water, acids, and chromates.
- susceptable to over washing with resultant loss of sensitivity.
- requires use of black light and darkened inspection area.

Apparatus

As with other liquid penetrant methods, the water washable fluorescent method can be performed entirely manually. The black light is the only apparatus absolutely necessary. However, additional apparatus is normally

employed for better control, for speed, and, in some instances for automation. Such apparatus with water-suspension developer is illustrated by the block diagram in Figure 26-4-2.

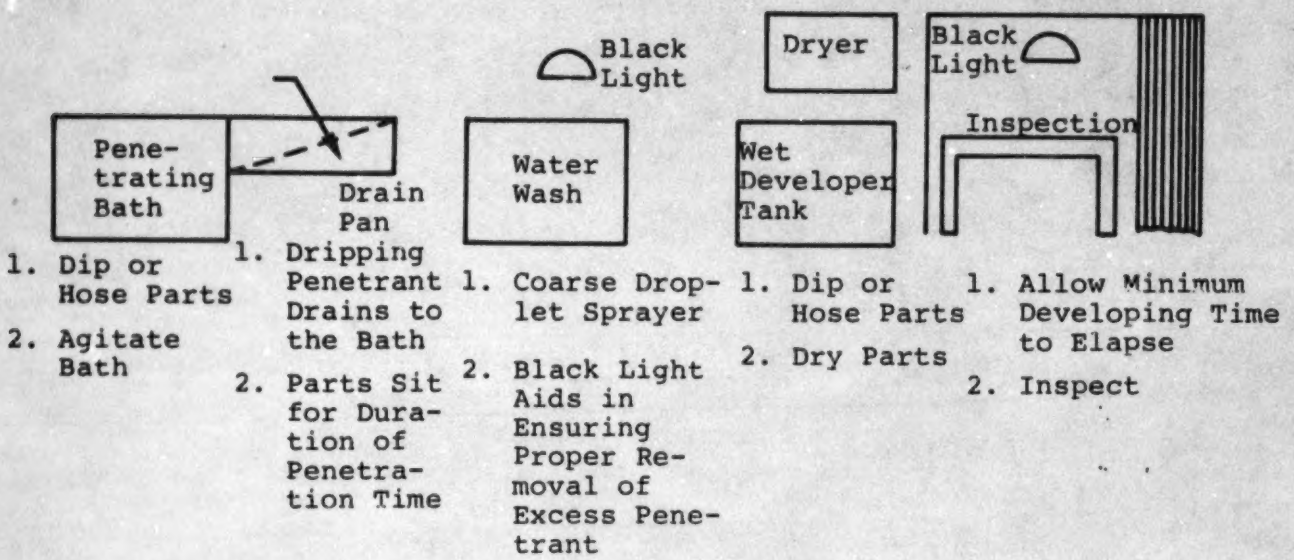


Figure 26-4-2 Block Diagrams of Apparatus for Water-Washable Fluorescent Penetrant Test

Procedure

Water-washable fluorescent penetrant examination procedures include the six essential steps previously described plus the important substep for drying. Unique factors involved with these steps are described as follows:

- precleaning - The precleaning step must avoid acid and chromate residues and must thoroughly dry the parts. Acids and chromates attack the fluorescent dye and seriously reduce the light emitted during fluorescence of indications. Therefore, if parts contacted acids or chromates in prior processing,

the precleaning step must thoroughly remove them. Water used in the precleaning step must be removed by drying because water activates the emulsifier in the penetrant.

- penetrant application - Dependent on the specific application, penetrant dwell time is typically 15, 30 or 60 minutes. Thirty or sixty minutes dwell times are typically used in applications requiring detection of very fine cracks.
- excess penetrant removal - Care is necessary to avoid water contamination of the nearby penetrant tank by water spray. A coarse droplet water spray is most effective for removal of excess penetrant. This type of spray readily activates the emulsifier and pushes excess penetrant away such that minimal washing is necessary. Wash water temperatures of 90°F to 110°F provide for excellent removal of excess penetrant. However, this temperature water typically washes away penetrant in shallow, open discontinuities.
- developing - If dry powder developer is used, the parts are first dried. Water-suspension developer is applied before drying. Circulating hot-air driers are typically used for drying. Air temperature should not exceed 250°F and part temperature should not exceed 125°F in order to avoid drying of penetrant and attendent loss of sensitivity. Developing time commences with application of the developer and is typically equal to minimum penetration time. The inspector must ensure that hands, equipment, and working surfaces are free from penetrant in order to avoid nonrelevant indications.
- inspection - Inspection commences at the end of the minimum developing time. It is accomplished within

a darkened area and with a black light which has been "on" for at least five minutes to allow adequate warm-up. Black light intensity at the surface to be examined should be a minimum 800 micro-Watts per square centimeter (mW/cm^2). Measurement of black light intensity is with special light meters calibrated in units of mW/cm^2. The meter is read at the surface without a filter and then read with an ultravoilet filter which blocks all ultravoilet light. The difference between the two readings equals the black light intensity.

- post cleaning - Post cleaning is typically by water wash. When the excess penetrant removal station is used for post cleaning, care is necessary to avoid water contamination of the nearby penetrant tank..

POST-EMULSIFIER FLUORESCENT METHOD

Advantages and Disadvantages

The post-emulsifier fluorescent penetrant examination process is very similar to the water-washable fluorescent penetrant examination process except that the emulsifier is added as a separate step. The fluorescence is more brilliant and emulsification of penetrant within discontinuities is avoided. Thus, advantages are realized with post-emulsifier fluorescent penetrant although there are also disadvantages.

Advantages

- excellent visibility.
- highest sensitivity to very fine cracks.
- not subject to over washing.
- good for shallow, open discontinuities.

Disadvantages

- additional step and equipment for application of emulsifier.
- difficult removal of excess penetrant on shapes with sharp contours, e.g., screws and slots.
- difficult removal of excess penetrant on very rough surfaces.

Apparatus

With the addition of emulsifier equipment, post-emulsifier fluorescent penetrant examination employs the same apparatus as for the water-washable fluorescent penetrant process. Addition of an emulsifier tank between the penetrant drain pan and water wash station in Figure 26-4-2 produces a block diagram of a typical post-emulsifier fluorescent penetrant process.

Emulsifiers are supplied as liquids which are applied by dipping, hosing, or spraying. Application by brushing is prohibited. Brushing mixes the emulsifier to various depths of penetrant such that some emulsification of penetrant within discontinuities is likely. Application by dipping permits essentially simultaneous covering and relatively easy control of emulsification time. Application by hosing or spraying has risk of inability to control emulsification time because of the time consumed in applying the emulsifier. Multiple hoses or sprays are sometimes used in lieu of dipping in order to provide a quick means of covering the entire surface with emulsifier.

Procedure

With the exception of the emulsification step, the procedure for post-emulsifier fluorescent penetrant examination is essentially the same as for water-washable fluorescent penetrant examination. Unique features are described as follows:

- penetration time - Typically, post-emulsifier penetrants require less penetration time than water-washable penetrants. Without the included emulsifier, the penetrant can be formulated to have better penetrability. Penetration times of 5 to 20 minutes are typical with the exact time dependent on the specific application.
- removal of excess penetrant - The key step is the application of the emulsifier and the time of emulsification. At the completion of penetration time, the emulsifier is applied quickly to the entire surface being examined. The emulsifier diffuses into the penetrant at a rate dependent on the specific type of emulsifier. The time permitted for emulsification is established by trial and error during procedure qualification and is typically on the order of 1 to 3 minutes. Each application establishes emulsification time at the minimum necessary in order to avoid loss of sensitivity. Insufficient emulsification time results in inability to wash all excess penetrant and, therefore, is evident by background indications. Excessive emulsification time results in emulsifying penetrant within discontinuities, especially shallow, open ones, and sensitivity is reduced. Proper emulsification time provides for easy removal of excess penetrant without loss of sensitivity. If proper emulsification time is achieved, excess washing is of no particular concern because the penetrant within discontinuities does not have an afinity of water. Since penetrant drains unevenly from parts with sharp contours and from very rough surfaces, it is difficult to properly emulsify all surfaces of such contours. For this

reason, water-washable fluorescent penetrant is more widely used for examination of threads and key-ways and for very rough surfaces.

COLOR-CONTRAST SOLVENT REMOVABLE METHOD

Advantages and Disadvantages

The color-contrast solvent removable liquid penetrant examination process requires the simplest of equipment, no black light and no water source. Containers for penetrant, solvent and developer and clean cloths are sufficient for performing this test. These features offer the following advantages although there are also disadvantages of this method:

Advantages

- highly portable.
- employs "normal" lighting (black light, darkened inspection area, darkness adaptation are unnecessary).
- good for a variety of discontinuites.
- small initial cost.

Disadvantages

- less sensitive to very fine cracks.
- less visibility of indications.
- more difficult "housekeeping" (red dye is conspicuous, messy, and removable only with solvents).

Apparatus

Container, brushes, and cloths are all that are required although pressurized spray cans are very popular with this method. If pressurized spray cans are used for penetrant, remover, and developer, clean cloths complete the necessary apparatus. When bulk containers are used, brushes are used

for application of penetrant unless the parts are dipped into the penetrant, and spray guns or brushes are used for application of the developer.

Procedure

The color-contrast solvent removable method employs the six essential steps previously described. Unique factors involved with these steps are described as follows:

- precleaning - As with other penetrant methods, thorough precleaning is necessary to remove surface materials which would otherwise interfere with the test. After cleaning and prior to application of penetrant, parts must be dry because cleaning solvents dilute the penetrant and water in discontinuities blocks penetration.
- application of penetrant - Penetrant is applied by brushing, spraying or dipping. Pressurized spray cans or brushes are most popular because only the surfaces to be inspected are wetted and it is less "messy". A liberal amount is applied to ensure complete wetting of the surface. Penetration time is typically from 5 to 20 minutes dependent on the particular application.
- removal of excess penetrant - This step and the developing step are most critical. In order to avoid excessive background indications, some solvent must be used. However, flushing the surface with solvent has high risk of removing relevent indications. Accordingly, excess penetrant is removed in two steps. First, dry cloth wipes are employed to remove visible penetrant from the surface. Then, the surface is wiped with a cloth dampened with solvent. Excess solvent in the cloth or overzealous wiping tends to remove penetrant from

discontinuities and loss of sensitivity occurs. Rough surfaces handicap removal of excess penetrant and promote more vigorous wiping to remove excess penetrant from recesses. Since this can destroy indications in smoother areas, roughness limits are normally specified for surfaces to be examined by this method.

- developing - The developer is white chalk suspended in a very volatile solvent. It is normally applied by spraying although brushing can be qualifed. Application of developer must result in a thin, uniform coating to provide for good blotting action and best contrast between the red dye and white developer. Care is necessary to avoid puddling such that the developer runs prior to evaporation of the solvent. Also, care is necessary to avoid caking, i.e., excessive thickness of the developer coating which masks indications. After application of the developer, a developing time must elapse prior to inspection. Developing time is generally ½ of dwell time.
- inspection - Inspection is carried out under sunlight or white light of sufficient intensity to ensure no loss of sensitivity. At least 30 to 50 footcandles at the surface is necessary. As with other penetrant methods, the inspection must be diligent, thorough, and cover the entire surface.
- postcleaning - After completion of inspection, the surface is cleaned with water or solvent wash or wipe. Water wash may require detergents to remove some developers.

DEFECTS

Liquid penetrant indications which are relevant and in excess of acceptance standards represent defects. In addition to reporting the existence of a defect, the liquid penetrant examiner typically must report size and type of defect. Reports of size and type of defect assist in the determination of corrective action by indicating the cause of the defect.

Penetrant examination cannot measure depth of defect. Only width and length of the indication can be reported. Linear indications are reported by length, appearance and type of defect. Terms which describe appearance are:

- sharp - Edges of the indication are well defined.
- fuzzy - Edges of the indication are ill-defined.
- smooth - Brilliance or color contrast is essentially constant for the entire length of the indication.
- fine - The indication has little width.
- broad - The indication has measurable width.
- irregularly rounded - A rounded indication with irregular circumference.
- regularly rounded - A rounded indication which approximates a circle.

Determining the type of defect represented by the indication requires knowledge of the history of the part. Each type of processing has inherent defects. Knowledge of which defects may occur helps the inspector in classifying indications.

Product history consists of three classifications: primary processing, finishing, and service. Each has characteristic defects.

Primary processing defects include all those produced by preparing material into initial useable form. This

group includes defects in ingots, billets, castings, forgings, rolled product and extruded product. Characteristic defects of this group are listed in Table 26-4-2.

Table 26-4-2

Primary Processing Defects

Material Form	Defect	Typical Indication Appearance
Castings	shrinkage cracks	fine linear
	cold shuts	fine linear or intermittent linear
	handling cracks	fine or broad linear
	surface inclusion	irregularly rounded
	gas blows	regularly rounded
Forgings	laps	very fine linear or curvilinear
	tears	broad linear or curvilinear
	bursts	fine and broad linear and curvi-linear
Billets	shrinkage cracks	fine or broad linear
	seams	fine linear
Rolled Products	laps	fine linear
	laminations (open to cross-sectional surface only)	fine linear
Tubing	tears	broad linear
	seams	fine linear
	pinholes	regularly rounded

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Finishing defects include all those introduced in the the manufacturer of parts. Finishing operations include forming, bending, heat treating, grinding, machining and welding. Characteristic defects of this classification are listed in Table 26-4-3.

Table 26-4-3

Finishing Defects

Finishing Method	Defect	Typical Indication Appearance
Material Upsetting (forming, bending, molding, straightening)	cracks	fine or broad linear
Heat Treating	quench cracks	fine linear, irregular pattern
	stress cracks	fine linear, irregular patter
Machining	tears	broad linear
Drawing	tears	broad linear
Grinding	cracks	fine linear
Welding	lack of fusion or penetration	fine or broad linear
	undercut	broad linear
	longitudinal and transverse shrinkage cracks	fine or broad linear

Service defects include all those which occur after the item is placed in service. These defects are typically caused by fatigue, corrosion, and stress-corrosion effects. Table 26-4-4 lists characteristic service defects.

Table 26-4-4

Service Defects

Defect	Typical Indication Appearance
fatigue crack	fine linear
stress-corrosion crack	fine linear
corrosion pitting	rounded

APPLICATION

When surface defects impair the suitability of a part, either magnetic particle or liquid penetrant examination is used to detect surface defects. Liquid penetrant examination is used for testing nonmagnetic metals such as stainless steels, nickel alloys, aluminum alloys and copper alloys.

In nuclear power plant applications, many piece parts and pressure boundary welds receive liquid penetrant examination. Requirements for these tests are found in system and component specifications and the ASME Boiler and Pressure Vessel Code. These requirements typically specify two rules with respect to the time of performing liquid penetrant examination:

- Perform liquid penetrant examination after completion of all processing which affects surface condi-

tions. This insures that after acceptance by liquid penetrant, the surface remains unchanged.

- For installed systems, perform liquid penetrant examination after hydrostatic testing of the system. This ensures detection of discontinuities which may be propagated by the stresses from hydrostatic testing.

The liquid penetrant method employed is often inconsequential because each method has adequate sensitivity in terms of the acceptance standards. Typical application of the three methods described by this module are as follows:

- post-emulsifier fluorescent - used by reactor core manufacturers or core components where detection of shallow discontinuities are required. Some tubing manufacturers also employ this method.
- water-washable fluorescent - used by many suppliers on small parts because of the ability of this method to simultaneously test multiple parts.
- color-contrast solvent removable - essentially used in all other applications. Used almost exclusively at the power plant construction site due to its mobility. Used for inspection of welded joints.

PERSONNEL CERTIFICATION

Personnel who perform liquid penetrant examination, evaluate its results, and determine its applications are qualified in accordance with SNT TC-1A, Recommended Practices for the Certification of Nondestructive Examination Personnel. SNT-TC-1A provides for three levels of certification which are comparable to typical job categories with a company's organization. These levels are:

- Level I - A Level I individual has sufficient training and experience to perform the test.
- Level II - A Level II individual is able to direct and carry out tests, set up equipment, interpret indications, and evaluate indications to applicable codes and specifications.
- Level III - A Level III individual is able to establish techniques, interpret codes and specifications, and designate particular tests methods and techniques to be used.

Supplement D to SNT-TC-1A describes recommended training programs for equipping candidates to become certified as Level I or Level II in liquid penetrant examination. The content of this module is comparable to the Level II training program.

Certification of Level I and II personnel is based on training experience and examination of each individual. Each company prepares a written practice which defines the prerequisite criteria for certification. Normally, the Level III examiner is responsible for determining if Level I and II candidates meet the certification criteria and for administering the certification examination.

Certification examination consists of physical, written, and operational examinations. Certification criteria typically consists of the following for liquid penetrant Level I and Level II certification:

- physical - Natural or corrected near distance visual acuity such that the applicant can read Jaeger Number 1 letters at 12 to 20 inches, or an equivalent near distance visual acuity test. Normal color perception using a medically approved color discrimination test.

- written - An 80% grade on a two part written examination. Part I examines knowledge of test principles. Part II examines knowledge of equipment, operating procedures and test techniques encountered in the candidate's specific job assignment.
- operational - Successful demonstration of performing the test and evaluating the results.

All certified personnel are required to annually repeat the physical examination for visual acuity. In addition, recertification every three years is required. Recertification may be based upon either continual satisfactory performance or re-examination.

LIQUID PENETRANT PROCEDURES

Whenever liquid penetrant examination is to be performed, a procedure is prepared and demonstrated as a satisfactory test for the particular application. Unless unique conditions exist, a given procedure is useful for a number of applications. In general, a given procedure is useful in applications where none of the following conditions are changed:

- prior processing does not include grit or sand blasting or acid cleaning.
- precleaning method is suitable for the expected types of "dirt" to be cleaned.
- same "family" of penetrant materials is used (Family of materials refers to the specific penetrant, developer and emulsifier when used which are mutually compatible as identified by the manufacturer of the materials).

Level II personnel may be responsible for drafting liquid penetrant examination procedures. Level III personnel are normally responsible for approving each procedure. In any event, each procedure must include the following:

- brand name and specific types of test materials including an applicable penetrant, penetrant remover, emulsifier, and developer.
- details of the precleaning method including cleaning materials, method of drying, and time allowed for drying.
- details of the method of penetrant application, the dwell time and the temperature limits.
- details of the method of removal of excess penetrant and drying the surface. If applicable, details of applying an emulsifier and emulsification time.
- details of applying developer, the developing time, and drying when water-suspension developer is used.
- reference to applicable acceptance standards.
- details of the post-cleaning method.

Once the procedure has been prepared, it is demonstrated by testing a part with known discontinuities in accordance with the procedure. Scrap parts or specially prepared test piece are used for demonstrating the effectiveness of the procedure. A widely used test piece is an aluminum panel prepared as follows:

- material - 3/8" thick aluminum alloy, type 2024-T-3, sheet or strip.
- site - 3 x 2 inches with the 3 inch dimension in the direction of rolling.
- preparation
  - mark the center of the top face with 950^{o}F temperature melting crayon.

- heat the center of the underside with gas burner or flame such that crayon marking melts in about four minutes.
- immediately quench the panel in cold water.

An aluminum panel prepared in the foregoing manner contains quenching cracks which serve as a good test of the sensitivity of liquid penetrant examination. Sometimes a transverse 1/16" x 1/16" center groove is cut in the panel to provide for two test surfaces such that two types of penetrant can be compared.

GLOSSARY

- angstrom unit, A - a unit employed to express wavelengths of light, that is, electromagnetic radiation. It is equal to 10^{-8}cm.
- background - the surface of the test part upon which the indication is viewed. It may be the natural surface of the test part, or it may be the developer coating on the surface. This background may contain traces of unremoved penetrant, fluorescent or visible, which if present, can interfere with the visibility of the indication.
- black light - light in the near ultravoilet range of wavelength (3200 to 4000 A), just shorter than visible light.
- black light filter - a filter that transmits ultravoilet radiation (3200 to 4000 A wavelength) while suppressing the transmission of the visible.
- bleedout - the action of the entrapped penetrant in spreading out from surface discontinuities to form an indication.

- blotting - the action of the developer in soaking up the penetrant from the surface of the discontinuity, so as to cause maximum bleedout of the liquid penetrant for increased contrast and sensitivity.
- capillary action - the tendency of liquids to penetrate or migrate into small openings, such as cracks, pits, or fissures.
- clean - free of interfering solid or liquid contamination on the test surface and within voids of flaws.
- contrast - the difference in visibility (brightness or coloration) between an indication and the surrounding surface.
- darkness adaptation - the adjustment of the eyes, when one passes from a bright to a darkened place.
- defect - a discontinuity that interferes with the usefulness of a part.
- developer - a material that is applied to the test piece surface after the excess penetrant has been removed and that is designed to enhance the penetrant bleedout to form indications. The developer may be a fine powder, a solution that dries to a fine powder, or a suspension (in solvent or water) that dries leaving an absorptive film on the test surface.
- developer, dry - a dry, fine powder developer that is applied to the test piece after the excess penetrant is removed and the surface dried, in order to increase the bleedout by means of capillary action.

- developer, solvent - a developer consisting of fine particles suspended in a volatile solvent. The volatile solvent helps dissolve the penetrant out of the discontinuity and bring it to the surface. It then dries out, fixing the indication.
- developer, wet (aqueous) - a developer usually supplied in dry form which is mixed with water to form a suspension of particles for use.
- developing time - the elapsed time necessary for the applied developer to bring out indications from penetrant entrapments.
- discontinuity - a material void condition abruptly departing from the normal surface homogeneity.
- drain time - that portion of the dwell time during which the excess penetrant, emulsifier, detergent remover, or developer drains off of the test piece.
- drying oven - an oven used for drying rinse water from test pieces.
- drying time - the time allotted for a rinsed test piece to dry.
- dwell time - the total time that the penetrant or emulsifier is in contact with the test surface, including the time required for application and the drain time.
- emulsification time - the period of time that an emulsifier is permitted to combine with the penetrant prior to removal. Synonymous with emulsifier dwell time.
- emulsifier - a liquid that combines with an oily penetrant to make it water-washable.
- emulsion - a dispersion of fine droplets of one liquid in another, which can be stabilized by the addition of an emulsifier.

- etching - a cleaning process for the controlled removal of surface material by chemical agents prior to penetrant application.
- evaluation - process of determining the severity of the condition after the indication has been interpreted. Evaluation leads to determining whether the part is acceptable, salvageable, or rejectable.
- family - the complete series of materials necessary to perform a specific process of penetrant inspection.
- fine crack - a discontinuity in a solid material with a very fine opening to the surface, but possessing length and depth greater than the width of this opening; usually depth is many times the width.
- flaw - See defect.
- fluorescence - the emission of visible radiation by a substance as the result of, and only during, the absorption of black light radiation.
- indication - that which marks the presence of a discontinuity, as the result of detectable bleedout of penetrant from the discontinuity.
- inspection - visual examination of the test piece after completion of the penetrant processing steps.
- interpretation - the determination of the significance of the indications from the standpoint of whether they are relevant or nonrelevant.
- nonrelevant indication - an indication that is not or cannot be associated with a discontinuity.
- penetrant - a liquid capable of entering discontinuities open to the surface, and which is adapted to the inspection process, by being made highly visible in small traces. Fluorescent penetrants fluoresce brightly under black light and visible

penetrants are intensely colored to be noticeable under visible light.

- penetrant, fluorescent - an inspection penetrant that is characterized by its ability to fluoresce when excited by black light.
- penetrant, post-emulsifiable - a penetrant that requires the application of a separate emulsifier to render the surface penetrant water-washable.
- penetrant, visible - a penetrant that is characterized by an intense visible color, usually red, that allows it to give contrasting indications on a white developer background.
- penetrant, water-washable - a penetrant with built-in emulsifier, which makes it directly water-washable.
- penetration time - See dwell time.
- post cleaning - the removal of penetrant inspection material residues from the test piece after the penetrant inspection process is completed.
- post-emulsification - a penetrant removal technique employing a separate emulsifier.
- precleaning - the removal of surface contaminant or smeared metal from the test piece so that it cannot interfere with the penetrant inspection process.
- rinse - the process of removing liquid penetrant inspection materials from the surface of an item by means of washing or flooding with another liquid, usually water. Also termed "wash".
- self-emulsifiable - describes a penetrant that spontaneously emulsifies into water, a property that allows it to be rinsed off with water with more control that if it actually dissolved in the rinse water. Also called "water washable". (See also penetrant, water-washable.)

- shallow discontinuity - a discontinuity open to the surface which possesses little depth in proportion to its width.
- solvent action - the ability of a liquid to dissolve another material.
- solvent remover - a type of volatile liquid that can dissolve penetrant and that is used to remove excess surface penetrant from test parts by appropriate hand-wiping techniques.
- temperature envelope - the temperature range over which a particular penetrant inspection test will operate.
- water tolerance - the amount of water that a penetrant or emulsifier can absorb before its effectiveness is impaired.
- water-washability - the property of a penetrant which permits it to be cleaned from the surface of a part by washing with water.
- water-washable penetrant - a type of penetrant which incorporates an emulsifier, thus giving it water-washability.
- wetting action - the ability of a liquid to spread out spontaneously over and adhere to solid surfaces.

EXERCISES

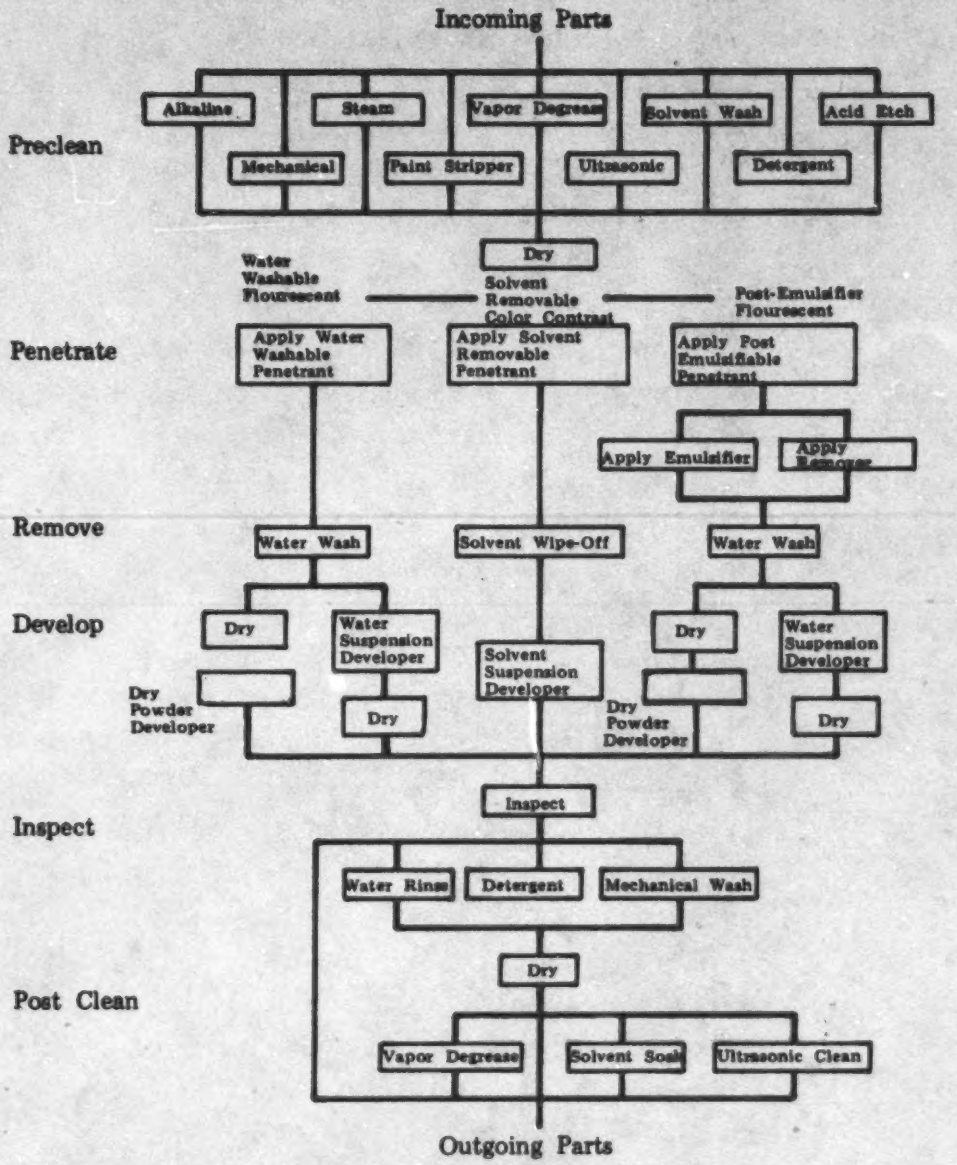
The following exercises serve to reinforce the concepts presented in this module.

1. Perform the Color-Contrast Solvent-Removal Penetrant test described in Procedure #1 of the Procedures section of this module.

2. Using Procedure #2, perform the Fluorescent Penetrant Test discussed in the Procedures section of this module.

3. Using Procedure #3 perform the preparation of an Aluminum Test Panel as described in the Procedures section.

4. Study the following block diagram and briefly explain the features associated with each method of liquid penetration examination.


Incoming Parts
Preclean
Alkaline
Steam
Vapor Degrease
Solvent Wash
Acid Etch
Mechanical
Paint Stripper
Ultrasonic
Detergent
Dry
Water Washable Flourescent
Solvent Removable Color Contrast
Post-Emulsifier Flourescent
Penetrate
Apply Water Washable Penetrant
Apply Solvent Removable Penetrant
Apply Post Emulsifiable Penetrant
Apply Emulsifier
Apply Remover
Remove
Water Wash
Solvent Wipe-Off
Water Wash
Develop
Dry
Water Suspension Developer
Solvent Suspension Developer
Dry
Water Suspension Developer
Dry Powder Developer
Dry
Dry Powder Developer
Dry
Inspect
Inspect
Water Rinse
Detergent
Mechanical Wash
Dry
Post Clean
Vapor Degrease
Solvent Soak
Ultrasonic Clean
Outgoing Parts

5. Answer each of the following questions as either true or false regarding the material presented in this module.

a.____ Liquid penetrant examination is employed for the detection of the surface discontinuities of non-porous materials. Capillary action is the basic principle of operation.

b.____ For each application, a liquid penetrant examination method is selected which has adequate sensitivity in terms of the type and size of defects to be detected as defined by the product acceptance standards.

c.____ Liquid penetrant examination is performed in accordance with detailed procedures by only professional engineers.

d.____ To assist in reporting the cause of defects, three classifications of defects are defined: primary processing defects, finishing defects, and service defects.

e.____ Primary processing defects in castings include shrinkage cracks, cold shuts, handling cracks, surface inclusions, and gas blows.

f.____ Primary processing defects in forgings include shrinkage cracks, cold shuts, and gage blows.

g.____ Primary processing defects in rolled products include laps, laminations, bursts, seams, and surface inclusions.

h.____ When liquid penetrant examination is required, it is performed after all processing which affects the surface conditions and, for systems, before hydrostatic testing of the system.

i.____ The most frequently used method at the nuclear power plant construction site is the color-contrast solvent-removable method.

j.____ Personnel certification is based on physical, written and operational examination.

k.____ Liquid penetrant examination procedures must include seven elements: specific penetrant material, precleaning method, penetrant application method, penetrant removal method, develcping, acceptance standards and postcleaning method.

l.____ The aluminum test panel is suitable for demonstrating the effectiveness of a liquid penetrant procedure.

MATERIALS

1. Color-contrast solvent removable penetrant portable test kit containing pressurized spray cans of penetrant, cleaner-remover, and developer.
2. Fluorescent penetrant portable test kit containing 100 watt black light and pressurized spray cans of penetrant, cleaner, and developer.
3. Ample supply of clean, lint-free cloths (about 8 per student/trainee).
4. Contact pyrometer or other device suitable for measuring surface temperature.
5. 950°F temperature melting crayons.
6. Metal buckets.

7. Bunsen burners or other flame heating source.
8. Aluminum alloy 3/8" sheet or strip.
9. Timers or wall clocks.
10. Parts to be inspected (preferably with surface defects).

PROCEDURES

1. Color-Contrast Solvent-Removable Penetrant Test
   A. Materials
      1. Portable test kit of color-contrast solvent-removable penetrant containing:
         a. penetrant
         b. cleaner-remover
         c. developer
         d. brush
      2. Clean, lint-free cloths (about 4 per student/trainee)
      3. Timer (wall clocks or wrist watches are suitable)
      4. Contact pyrometer or other temperature measuring device
      5. Parts to inspect (parts known to contain surface discontinuities are preferred)
   B. Procedure
      1. Clean part by spraying with cleaner-remover and wiping with a clean cloth.
      2. Allow part to dry for three to five minutes.
      3. Measure temperature of the part. If it is between 60°F to 125°F, preceed. If not, warm or cool the part as necessary to stay within 60°F and 125°F.

4. Spray penetrant on surface to be examined; ensure wetting of entire surface.
5. Allow a 15 to 20 minute dwell time.
6. Remove excess penetrant by wiping with a dry cloth.
7. Spray cleaner-remover onto a clean cloth. Squeeze the cloth to extract excess cleaner-remover. Wipe the surface to be examined with the dampened cloth.
8. Immediately agitate developer by vigorously shaking the can and then spray developer onto surface. Ensure application of a thin, continuous coating of developer.
9. Allow 7 minutes for developing time.
10. Inspect the part. Make a sketch of the part identifying relative location, shape, and size of each indication.
11. Postclean the part by wiping with a dry cloth followed by spraying cleaner-remover on the part and additional cloth wipes.

C. Operational Experiment

1. If the foregoing procedure revealed indications, this optional experiment may be performed to obtain an appreciation of dwell time.
2. Commencing with precleaning repeat the previous procedure described in B but allow a one minute dwell time. That is, one minute after applying penetrant, remove the excess penetrant.
3. Compare indications with those initially detected.

2. Fluorescent Penetrant Test

A. Materials

1. Portable fluorescent penetrant test kit consisting of:
   a. portable black light (100 watt, 115 vac)
   b. penetrant
   c. developer (spray can or dry powder)
   d. cleaner
2. Clean, lint-free cloths (about 4 per student/trainee).
3. Timer (wall clock or wrist watch suffices).
4. Contact pyrometer or other temperature measuring device.
5. Parts to inspect (parts with known surface discontinuities are preferred).

B. Procedure

1. Clean part by spraying with cleaner solvent and wiping with a clean cloth.
2. Allow three to five minutes for the part to dry.
3. Measure temperature of the part. If it is between 60°F and 125°F, proceed. If not, warm or cool the part as necessary to maintain it within these temperatures.
4. Spray penetrant onto surface to be examined; ensure wetting of entire surface.
5. Allow a 5 to 10 minute dwell time.
6. Spray cleaner liberally onto a cloth. Squeeze cloth to remove excess cleaner. Using the dampened cloth, wipe excess penetrant from the surface. If necessary, repeat this step with another cloth.

7. Immediately agitate developer by vigorously shaking the spray can and then spray developer onto the surface such that a thin coating is obtained.
8. Allow a 5 minute developing time.
9. Inspect the part under black light. Make a sketch of the part identifying relative location, shape and size of each indication.
10. Postclean the part by spraying cleaner onto the surface and wiping with clean cloths.

3. Preparation of an Aluminum Test Panel

A. Materials

1. Aluminum alloy 3/8" sheet cut into 3" x 2" panels.
2. Bunsen burner or other flame heating source.
3. 950°F temperature melting crayon.
4. Metal bucket or pail, 1 or 2 gallon capacity.
5. Stand and clamps.
6. Tongs.

B. Procedure

1. Mark the center of the upper face of the test panel with the temperature melting crayon.
2. Clamp test panel in a stand with marked surface up and suitable for applying heat source to under side of panel.
3. Fill pail with water and place it conveniently nearby.
4. Apply heat to underside of panel until crayon marking melts. Note time taken for this step.
5. Hold test panel with tongs, quickly unclamp the panel, and promptly drop the panel into the pail.

6. Wait about two minutes.
7. Remove test panel from pail.
8. Liquid penetrant test the panel in accordance with Exercise #1 or #2.
9. If there are no indications on the test panel, repeat this exercise but place the heat source closer to the panel.

DATA TABLE

None.

REFERENCE MATERIALS

American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, Specifications:

E165 Standard Recommended Practice for Liquid Penetrant Inspection Method

E270, Standard Definitions of Terms Relating to Liquid Penetrant Inspection

E433, Standard Reference Photographs for Liquid Penetrant Inspection.

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III and V, ASME, New York, N.Y.

R.C. McMaster, for SNT, Nondestructive Test Handbook, Vol. 1, The Ronald Press Company, New York, New York, 1959.

W.J. McGonnagle, Nondestructive Testing, McGraw-Hill Book Company, Inc. New York, New York, 1961.

"Inspection of Welding". Welding Handbook, Section 1. latest edition, American Welding Society, New York.

C.E. Betz, "Principles of Penetrants", Magnaflux Corporation, Chicago, Illinois, 1963. Available from SNT.

Liquid Penetrant Testing, General Dynamics Corp. From American Society Nondestructive Testing, Evanston, Illinois 1967. PI-4-2, CT-6-2. 2 Volumes.

TEST

Match the liquid penetrant examination method with its characteristics by placing the appropriate letter from the right hand column adjacent the characteristic in the left hand column:

Characteristics

___ 1. Best for detecting shallow open discontinuities.

___ 2. Most susceptible to water contamination.

___ 3. Simplest in terms of equipment.

___ 4. Susceptible to loss of indications by water washing.

___ 5. Highest sensitivity to very fine cracks.

___ 6. Most portable.

Method

A. Water-washable fluorescent

B. Post-emulsifier fluorescent

C. Solvent-removable color-contrast

Answer the following questions:

7. Why should the water spray used in removing excess water-washable or post-emulsifier penetrant be comprised of coarse droplets at moderate pressure?

8. Name three deleterious contaminants which should be avoided with water-washable fluorescent penetrant.

9. What dry method is typically used with water-washable and post-emulsifier fluorescent penetrant methods.

10. Define darkness adaptation and explain its function.

11. Describe why emulsification time is critical with respect to the post-emulsifier fluorescent penetrant method.

12. Describe how excess penetrant is removed in the solvent-removable color-contrast penetrant method.

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Arrange the steps listed in the proper sequence for the penetrant method and line-out steps that do not apply to the method.

13. Water-washable fluorescent penetrant method
    a. Spray solvent-suspension developer
    b. Dip item in penetrant
    c. Coarse spray water wash
    d. Vapor degrease
    e. Hose water-suspension developer
    f. Drain parts for duration of dwell time
    g. Force-air dry
    h. Inspect
14. Post-emulsifier fluorescent penetrant method
    a. Detergent clean
    b. Apply emulsifier
    c. Forced-air dry
    d. Inspect
    e. Postclean
    f. Spray penetrant onto item
    g. Dip in dry powder developer
    h. Coarse spray water wash
15. Color-contrast solvent-removable method
    a. Coarse spray water wash
    b. Solvent wash
    c. Spray penetrant onto item
    d. Inspect
    e. Spray solvent-suspension developer
    f. Dry wipe
    g. Wet wipe
    h. Apply emulsifier